

# Recent Improvements in the FDNS CFD Code and its Associated Process

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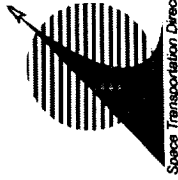
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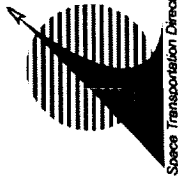


## OVERVIEW

- Motivation
- Discussion of Process, Limitations, and Improvement
- Process and Code Improvements
- Ongoing Improvements
- Summary and Future Plans

## Motivation

- NASA 2<sup>nd</sup> Generation (SLI) Launch Vehicle Reliability Requirements are Ambitious
- Using CFD as numerical experiments provides an opportunity to reduce the number of physical experiments required to define a successful design *if and only if CFD results can impact the Engineering Process*
- Typical CFD Analysis Procedure is:  
Grid Generation, Pre-Processing, Execution, Post Processing  
(GPEP)
- Where is Engineering?



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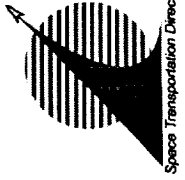
## Recent Improvements in the FDNS CFD Code and its Associated Process

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### Motivation (cont'd)

- Only after Analysis Process is completed can Engineering take place
- Our need/goal is to minimize the minimize the effort for GPEP in order to maximize the effort for Engineering
- FDNS has been developed over the last dozen years by a teamwork between NASA/MSFC and its contractors
- FDNS has a legacy of advanced and unique models successfully supporting NASA programs, however, FDNS requires considerable manual/interactive effort to accomplish a flow solution



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### Process Limitations (Process Definitions)

1. Grid Generation
  - Gridgen (Pointwise), Custom Grid Templates (Miss. State - ERC)
  - Not a target of this effort
2. Pre-Processing
  - Grid File, Initial Conditions File, Input Control File (Chemistry Specification, BCs, Iteration Control, Output Control)
3. Execution
  - Serial/Parallel, Domain Decomposition, Solution Monitoring
4. Post Processing
  - Quality Control, Refined Product Identification/Computation, Feature Detection

## Process Limitation and Improvement Definition

- Process Limitation: Obstacle to Achieving Goal (Subjective)
- Obstacles identified by observation of common experiences
- Obstacles are due to accessibility of features and large number of models from aggressive development
- Removing generality or ability does not result in Improvement
- An Improvement must enhance the Generality, Simplicity, and Effectiveness of the Process

## Process Limitation: Boundary Condition Specification

- Input Control File: BC setup is not scalable by human means
  - I/O Boundaries: 13 values on 1 line
  - Wall Boundaries: 12 values on 1 line
  - Zone Boundaries: 17 values on 2 lines
  - Not uncommon to have over 100 boundaries to specify
- Verifying BC's requires reference to grid values
- PreViewer was created, a batch and/or GUI application
  - Unix Prompt> Previewer -batch grid\_file input\_control\_file
- Eliminates 95+% of human error

## PreViewer Summary

- PreViewer Features
  - Zero/Multiple BC Definitions (Awareness is 90% of the battle)
  - Verification of Block Boundary Alignment
  - Objective evaluation, catches bugs in grid generator and flow solver alike
  - Visualization of boundary information
  - Boundary Condition combination/coalescence
- Application Details
  - PreViewer is limited to supporting FDNS
  - Portable, requires only C++, Qt, and OpenGL
  - Verified on SGI, Linux-Intel, Solaris, should work on (HP-UX, Linux-Alpha, Win32)
  - Available upon request  
<http://techtran.msfc.nasa.gov/software/previewer.html>
  - Extendable, have algorithm, will implement

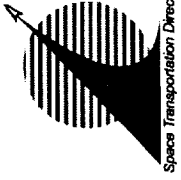


## Process Limitation: Code Version Control

- Multiple Versions
  - FDNS has been developed aggressively and concurrently by multiple entities
  - Multiple versions with conflicting models and heritage
- CVS (Concurrent Versions System)
  - Manual attempts ultimately failed due to inability to keep pace with development
  - CVS eliminates a large portion of human effort required to maintain a consistent code base for multiple users
  - Provides near-perfect documentation (the culprit can be identified)

## Process Limitation: Code Consistency Control

- Ongoing Development Poses a Threat to Code Base Maturity
  - Code Enhancement must continue on a constant basis
  - Awareness of how a best-prediction changes with improvements is a necessity
  - Rarely-used but valuable capability must be retained
- ATS (Automated Test Suite)
  - Manually maintaining a suite of check cases at the frequency of improvements is not practical
  - Automated Pre-Processing, Execution, and Post-Processing
  - Stringent comparison of new code results to ‘accepted result’
  - The ideal Suite of check cases would be mutually orthogonal



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# Automated Test Suite Summary

- Features
  - Sets up and runs case identically each time
  - User configurable threshold of comparison to ‘accepted’ results
  - Pass/No Pass notification by email
  - Allows selection of all or subset of Cases
  - Parallel execution on shared memory architectures
  - Portable, GUI-driven, Unix C++/Qt Application
  - Robust, Fire and Forget
  - Potentially available via CVS



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### Automated Test Suite Summary, (Cont'd)

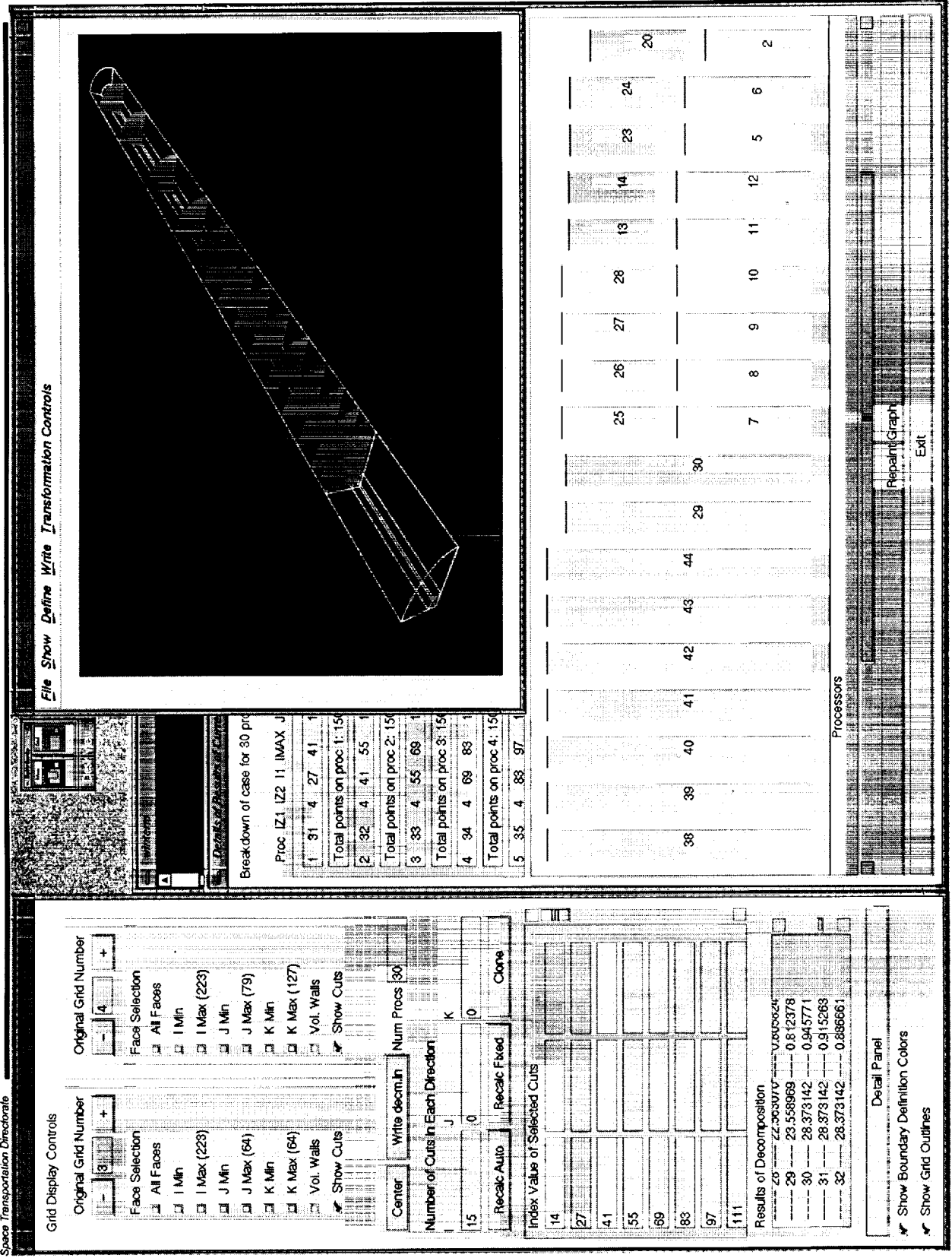
Improvement	Description	Completion Date
Enhanced Plot3D Output	Allows run-time alterations of requested output variable	3-x-2002
Real Fluids Capability	Allows constant pressure model of real fluid properties of LOX (LH2 soon)	4-3-2002
Improved Accuracy Block Boundary BCs	Improve the accuracy of block boundaries to allow massive domain decomposition	5-?-2002
Time Accurate Transient Simulation	Re-implement Time Accurate capability in the code	6-?-2002

## Process Limitation: Domain Decomposition

- FDNS accomplishes parallel operation by domain decomposition
  - Number of BCs can increase from 6 to hundreds or thousands
  - How does one specify grid decomposing strategy for load balancing?
  - How does one compute required zone BCs once grid decomposition is specified?
  - How does one decompose/recompose the grid and initial conditions files once mapping is defined?
- PreViewer's Interactive Decomposer and Load Balancer
  - Creates decompose map file
- PreViewer's -fullDecompose and -recompose modes
  - Unix> Pre Viewer -fullDecompose init\_file grid\_file control\_file map\_file new\_init new\_grid new\_control
  - Unix> Pre Viewer -recompose format decomposed\_file map\_file recomposed\_file



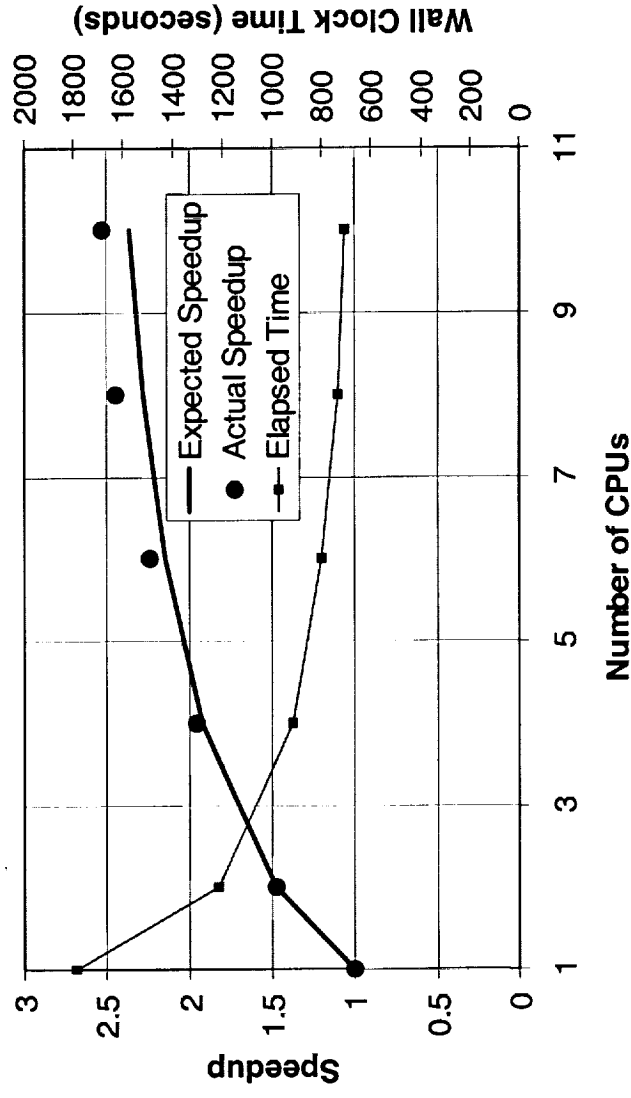
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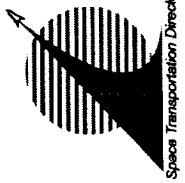


## Domain Decomposition, (cont'd)

- Domain Decomposition may not be desirable for all problems
- (Ongoing Work) One alternative is to implement multi-threaded parallelism (OpenMP). Cooperative effort with NASA/AMES support staff has completed OpenMP implementation of chemistry module

$$\lim_{n \rightarrow \infty} \text{speedup} = \frac{\text{total CPU time}}{\text{Serial Time} + \frac{\text{Parallel Time}}{n}} = \frac{100}{35.9 + 0} = 2.7855$$





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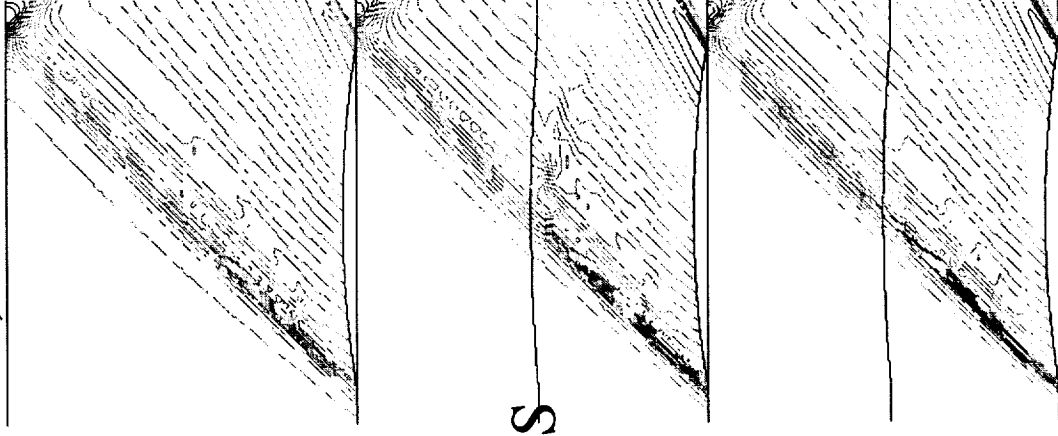
### Domain Decomposition, (cont'd)

- (Ongoing with ESI) Ultimate solution is to implement block boundaries that are numerically identical to the numerical scheme at the internal point
- Significant improvement has been obtained
- Once completed, this improvement will be incorporated into the main-line code

#### Single Block

#### FDNS500-CVS

#### Interim Result





## Summary and Future Work

- The development of a utility, PreViewer, has essentially eliminated the creeping of simple human error into the FDNS Solution process
- Extension of PreViewer to encapsulate the Domain Decomposition process has made practical the routine use of parallel processing
- The combination of CVS source control and ATS consistency validation significantly increases the Efficiency of the CFD process

## Summary and Future Work, (cont'd)

- Harness Parallel Resources
  - Transient Simulations
  - 3D problems (multiple element injectors)
  - Hardware:
    - NASA/AMES: Large MP platforms
    - NASA/MSFC: 100 node, 200 CPU AMD Athlon MP-based Linux Cluster
- Address Multiple Phase Problems
  - Fuel injector environment definition (conjugate heat transfer)
  - Rocket Chamber and Nozzle Regenerative Cooling
  - Real Fluid Property Simulation
- Automated Grid Generation
  - Close coupling of grid generation to source CAD database